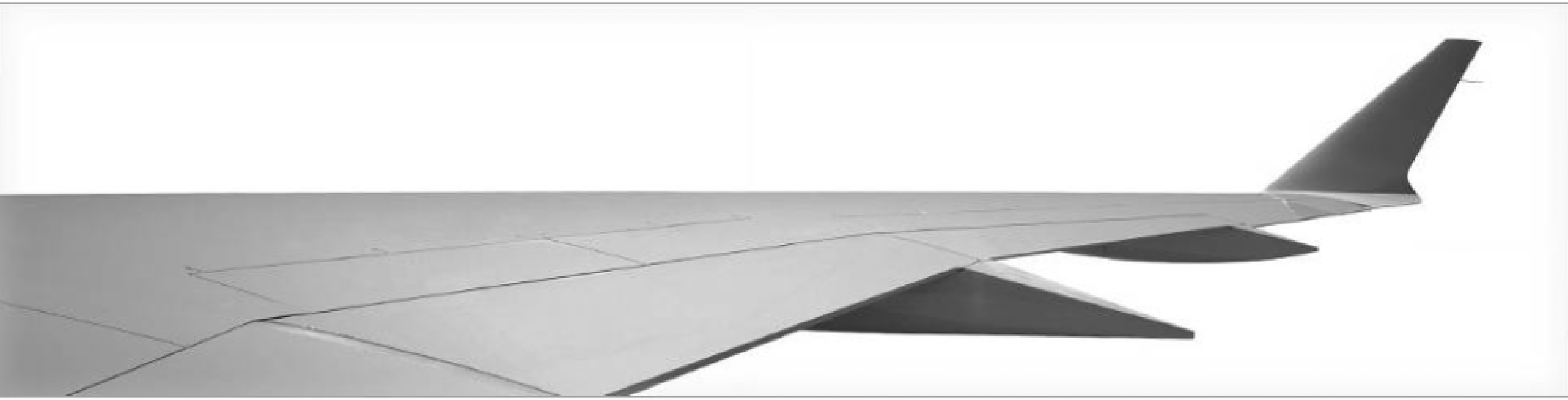
CRJ 200/SN 7396 Accident Investigation
Performance Panel Meeting
Montreal November 15th 2004



Package 1

Bombardier Proprietary Data

BOMBARDIER

Introduction

This presentation was requested by the performance panel.
It addresses questions and requests raised by the panel.
Note that not all the questions have been addressed fully in this presentation due to time restraint on specialists.
BA will provide full explanation as soon as possible.

General Information

Weight Information as provided by Dan Bower (11/09/04) “from operations Group chairman, dispatch take-off weight was 39239 lbs, ZFW was 31436 lbs, and c.g. was 21.6%”

Bombardier Weight Calculation;
Using FDR Fuel quantity to calculate take-off weight at BRK release and weight at 41,000 ft:
ZFW: 31436 LB (as per NTSB)
Fuel quantity at BRK rel (lb): 3968/3968   Frame No. 179880
Fuel quantity at 41,000 ft   : 3168/3200   Frame No. 181676
<u>Take-off weight 39372 lb</u>
<u>Weight at 41,000 37804 lb</u>

CRJ 200/SN 7396 Accident Investigation
Performance Panel Meeting

- **Pierre Huggins (ALPA)**
- **Captain Santi Lombardo (Northwest Airlink)**
- **Bob Perkins (GE)**
- **Ali Khalili (BA)**
- **Clinton E. Tanner (BA)**
- **Don Stephen (TC)**
- **Rodrigo J. Huete (FAA)**
- **Daniel Bower (NTSB) Chairman of the Group**

Presentation to NTSB – November 2004
CRJ-200 SPS AOA Vane Limits of Operation

CRJ-200 Maximum Stall Vane Angle:

- The angular range of the original CRJ200 AOA (P/N 45-130-340 or BA P/N 601R50154-1) is +43 +/- 1.5 to -43 +/- 1.5 based on the ATP for end stop settings. The value shown on the FDR is this + aircraft correction then converted to body angle.
  - Ref: Sextant Report J17245AA Acceptance Test Procedure for Angle of Attack Sensor P/N 45 150 340.

- Since the end of last year, the AOA could have been replaced by a C16258AA, which has end stop settings of +43 +/-3 to -43 +/-3.
  - Ref: Sextant Report Z1273426 (ST670-598-01) Acceptance Test Procedure for Angle of Attack Sensor P/N C16258AA.

4th November NTSB Performance Group Meeting - Action Closed

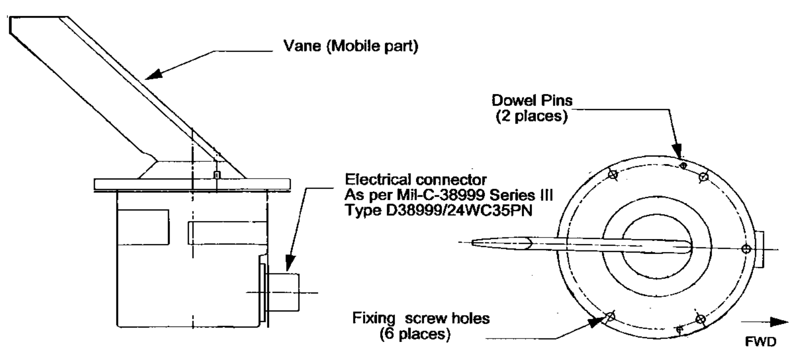
Presentation to NTSB – November 2004
CRJ-200 AOA_{Vane} to AOA_{Body} Angle Conversion

- **Equation for conversion from AOA_{Vane} to $AOA_{Body(Fuselage)}$ – valid for all flap angles**, Ref. FSW/91/601R/073/VT**;**
  - $\alpha_{FUSELAGE} = 0.845 + 0.602 * \alpha_{STALL\ VANE}$

4th November NTSB Performance Group Meeting - Action Closed

Presentation to NTSB – November 2004
CRJ-200 SPS

- ❖ The RJ-200 is fitted with a dual channel digital Stall Protection System (SPS) which provides high AOA (angle of attack) protection for the engine (auto-ignition), artificial stall warning (stick shaker) and stall identification (stick pusher).
- ❖ The Stall Protection System (SPS) comprises a Stall Protection Computer (SPC), two AOA vanes mounted on the left and right forward fuselage sides, a shaker motor on each control column and a pusher motor mounted on the co-pilots column.
- ❖ The SPC uses flap position and Mach to calculate the firing angle for the engine auto-ignition, shaker and pusher.

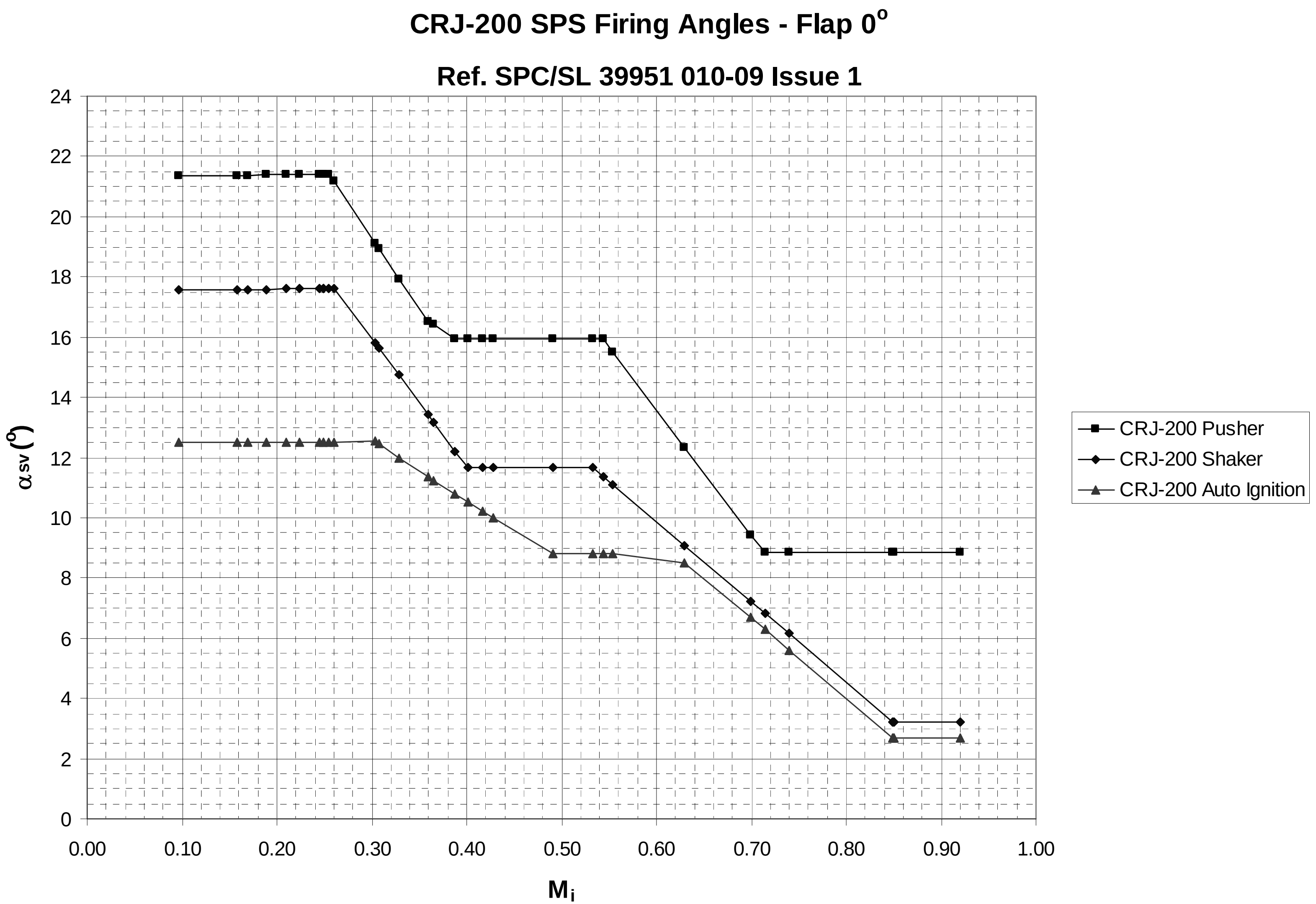


Presentation to NTSB – November 2004
CRJ-200 SPS

- ❖ **Implemented within the SPC are look-up tables, which define the AOA firing angles for the "auto-ignition", "stick shaker" (stall warning) and "stick pusher" (stall identification). The RJ-100/200 SPC look-up tables are functions of Mach number and flap angle.**

- ❖ **The SPS pusher firing angles at Mach No's above 0.55 have been defined by the engine operating envelope.**

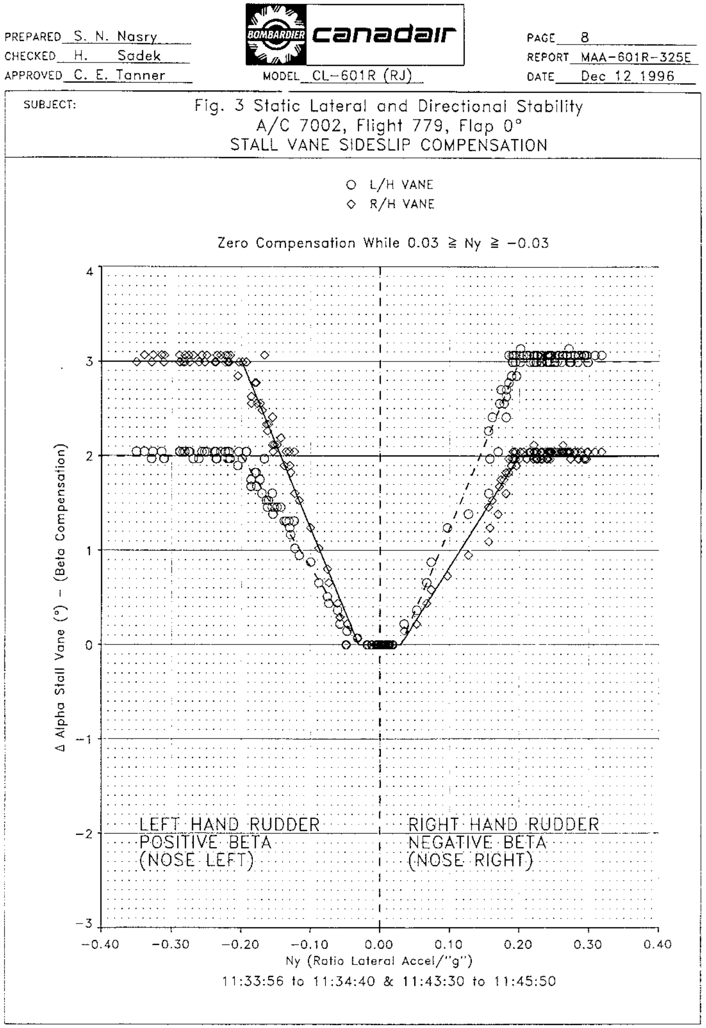
Presentation to NTSB – November 2004
CRJ-200 SPS



Presentation to NTSB – November 2004
CRJ-200 SPS - "Sideslip Compensation"

- ❖ **The airflow around the circular fuselage affects the AOA vanes in sideslip.**

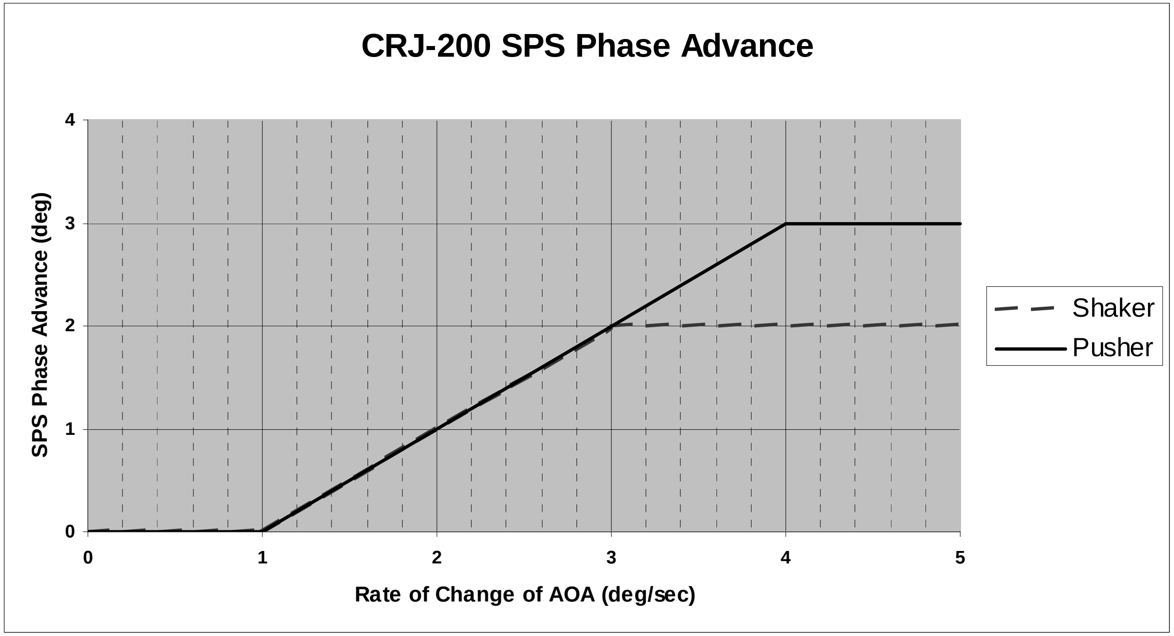
  - ◆ **The SPC compensates the measured stall vane AOA for the cross-flow induced effects on the windward and leeward AOA vanes in sideslip. The SPC adjusts the left and right vane AOA signals to compensate for the sideslip effects using lateral "G" from the IRU/AHRS as a programmed substitute for sideslip angle. To reduce sensitivity to gusts and turbulence the vane AOA signals are filtered.**



Presentation to NTSB – November 2004
CRJ-200 SPS Functionality

- **To protect the aircraft from inertial overshoots during accelerated stall entries at low speed the SPC incorporates an AOA phase advance function. This function reduces the shaker and pusher AOA firing angles in direct proportion to the rate of increase of AOA, up to a pre-set maximum.**
- **The CRJ100/200 phase advance on the shaker is not enabled until three seconds after weight-off-wheels during take-off, and is then phased in progressively over one second.**
- **The pusher retains its phase advance throughout the take-off. The phase advance for shaker and pusher is disabled above a pre-set Mach number (M>0.52).**

Presentation to NTSB – November 2004
CRJ-200 SPS Functionality



		CRJ-200
Phase Advance "cap"	Shaker	2
	Pusher	3
Phase Advance Time Delay After WOW	Shaker	3+fade in
	Pusher	0

Presentation to NTSB – November 2004
CRJ-200 SPS Functionality

- **If the signal from one of the AOA vanes exceeds the programmed “auto-ignition” firing angle, it will cause the activation of both engine auto-ignition systems.**
- **At a higher AOA, and if the signal from one of the AOA vanes exceeds the programmed “shaker” firing angle, it will cause the activation of the stick shaker motor on that side. Both the pilot and co-pilot’s sticks will shake because they are mechanically connected. If both AOA vanes exceed the “shaker” firing angle, both stick shaker motors will be activated.**
- **At even higher AOA, and if the signal from one of the AOA vanes exceeds the programmed “pusher” firing angle, it will trigger the “stall” aural warning and the onside “STALL PUSH” warning light. If both vane AOA’s exceed the “pusher” firing angle the stick pusher motor will be activated. The stick pusher motor will apply an approximately 80 lbs forward force to the control columns.**

Presentation to NTSB – November 2004
CRJ-200 SPS Functionality

- **The motor will cease to be active, and the 80 lbs push force removed, once the AOA of the aircraft reduces below a preset value below the pusher threshold (hysterisis).**
  - **To reduce the tendency to pitch down to less than zero "g" during high altitude pusher stalls, the pusher hysterisis is reduced as a function of the a/c nose down rate of change of AOA see next slide;**

- **The SPC also provides normalized AOA data for other aircraft systems e.g. the "green line" (FAA aircraft only), the barber pole low speed cue, and the Windshear detection and guidance systems.**

Presentation to NTSB – November 2004
CRJ-200 SPS Functionality

- **Pusher Cancellation Term,** Ref. MAA-601R-325:
  - **The pusher activate signal shall be removed when the angle of attack is reduced below the pusher threshold by the hysteresis amount defined below:**

    - $\alpha_{\text{CANCEL}} = \alpha_{\text{F PUSH}}$ **– hysterisis**

    - **Where:**

      hysterisis = 5.5$^\circ + 0.75 * \delta\alpha/\delta$**t**

    $\delta\alpha/\delta$**t is the rate of change of angle of attack.**

Presentation to NTSB – November 2004
CRJ-200 SPS Functionality

- **High Altitude Stalls;**
  - **The stick shaker is programmed to activate slightly ahead of the buffet boundary at M>0.52.**
  - **The shaker action is considered to be timely and distinct.**
  - **Stall identification is by the nose down pitch due to the stick pusher.**

4th November NTSB Performance Group Meeting SPS Functionality – Action Closed

Presentation to NTSB – November 2004

CRJ-200 - Aircraft Sideslip Angle Derived from Left and Right AOA Vane differences

- **The AOA output from the SPS, and recorded on the FDR, is converted into body angle and is also corrected for the effects of "sideslip" (sideslip compensation).**
- **To calculate sideslip angle from differential Left and Right AOA the "sideslip compensation" would have to be removed.**
  - **The sideslip compensation is a function of the lateral "g"; Ny.**
  - **The relationship between differential AOA and sideslip angle is very complex.**
- **A more direct and simple method to determine the approximate Sideslip angle is to use the flight measured Ny versus sideslip(β) relationship. The folowing equation was developed from data contained in the CRJ-200 Lateral/Direcional Stability certification report, MAA-601R-307;**
  - $\Delta Ny / \Delta\beta = -6.9 * 10^{-7} * V^{**}2$ **("g"/deg)**

4th November NTSB Performance Group Meeting - Action Closed

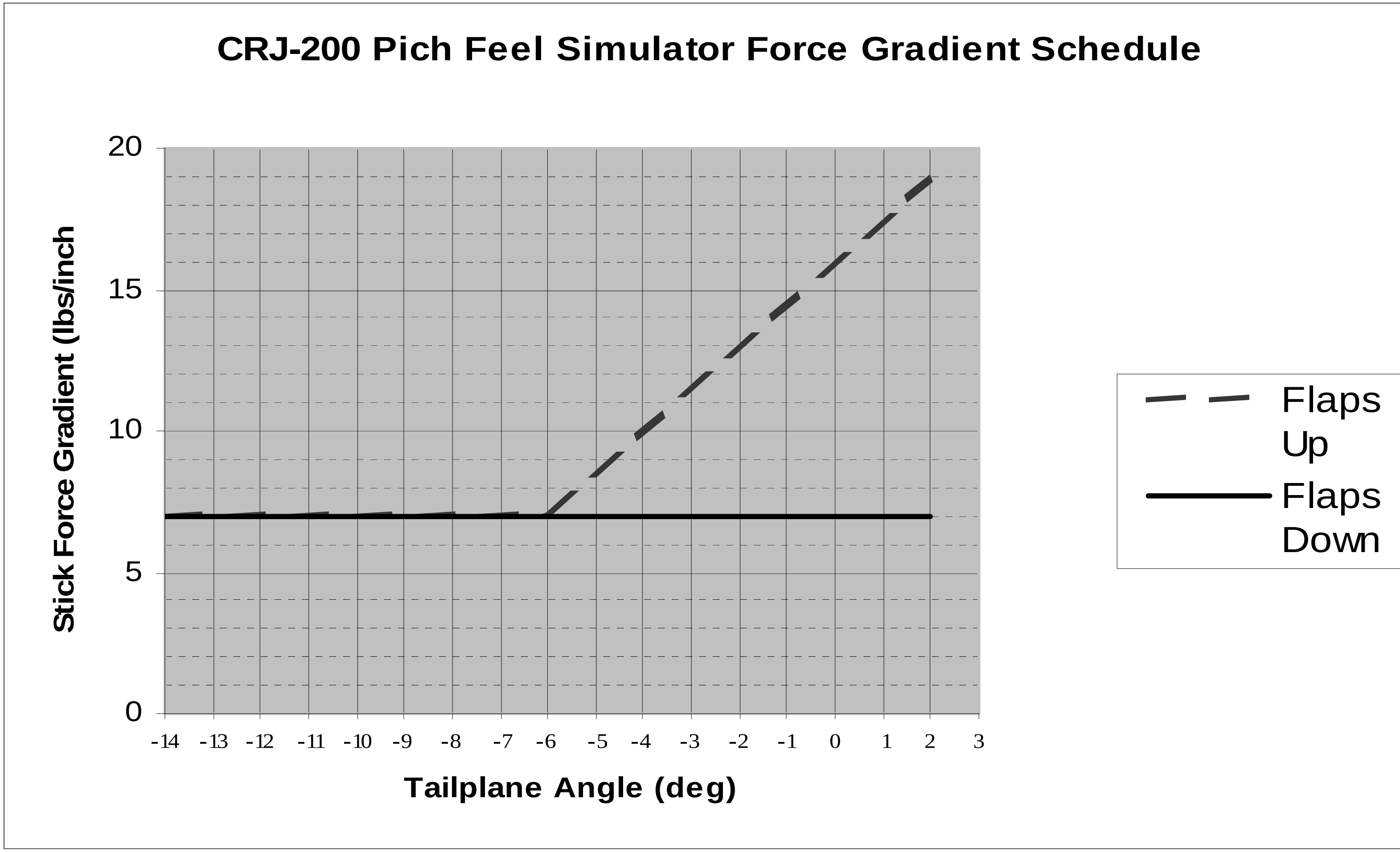
Presentation to NTSB – November 2004

CRJ-200 – Hands Off Column Position After Pusher Release

- The SPS pusher motor will disengage, and the 80 lbs push force removed, once the AOA of the aircraft reduces below the pusher cancellation threshold.
- Typically the control column will have been taken from the pilots hands during the initial “push” and will move forward of the control column “neutral” position.
- Following the removal of the 80 lbs pusher force, the remaining force acting on the control column will be the centering force applied by the pitch feel simulator unit.
- The pitch feel simulator unit provides an artificial “stick” force to the control column, which is a direct function of the position of the stick away from neutral.
- The pitch feel unit forces are provided by mechanical means, utilizing springs and levers, and the force gradients are varied as functions of the horizontal stabilizer position (pseudo “q” feel) and flap position.
- “Hands free” the displaced control column will therefore return to the neutral position.

Presentation to NTSB – November 2004

CRJ-200 – Hands Off Column Position After Pusher Release



4th November NTSB Performance Group Meeting - Action Closed

To examine all the high altitude certification flight test data, including traces of flight parameters, including information on certification dual engine flameout –, (test flight 320 and 205), to include standard aerodynamic, engine, and engine start parameters.

- **The flight traces will be presented for review.**

Clarification of power setting lookup data above 37,000 feet - what is the accuracy of the data above 37,000 feet.

AFM Limitation:

The FMS calculated thrust setting must not be used if the pressure altitude is greater than 36,000 ft
(Ref: TR RJ/139, Apr 28/04)

Reason:

The implementation of the conversion from SAT to the ISA deviation is incorrect within FMS.
Instead of ISA being –56.5 °C above ≅ 36,000 ft, it was calculated using lower altitude temperature lapse rate.

Level of Accuracy:

The error in thrust setting (N1 setting) can be as much as ± 2% N1 at 41,000 ft.

4th November NTSB Performance Group Meeting - Action Closed

Q. How does the simulator model for high altitude compare with the flight test data available?

A. Data review with simulation specialist. See Traces will be supplied.

Q. What form does the simulator data exist (linear mode or table lookup)?

A. Table lookup.

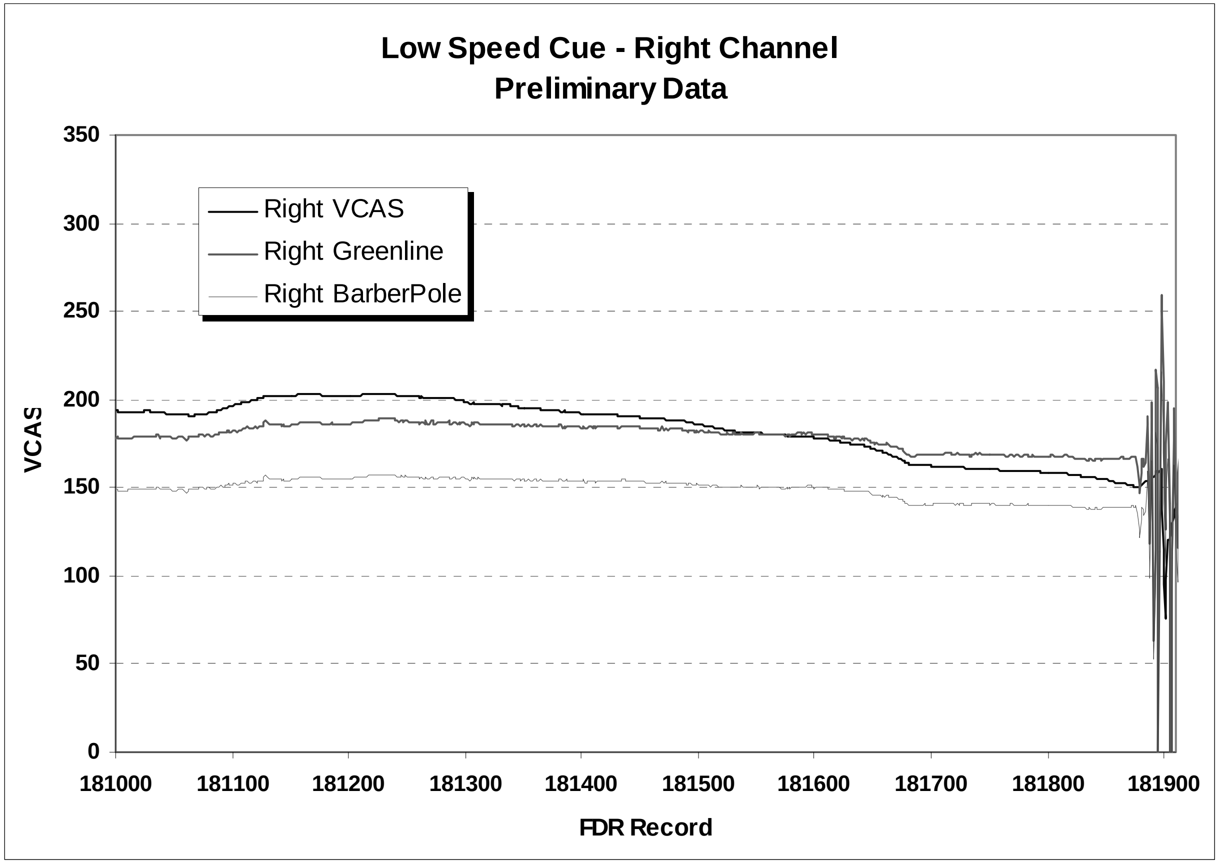
4th November NTSB Performance Group Meeting - Action Closed

Presentation to NTSB – November 2004
CRJ-200 Green Line and Barber Pole

- **Simulation time history of the low speed cue and green line as displayed to pilots through the climb from 37000 ft to 41000 feet for the accident flight;**
  - $V_{Barber\ Pole} = 1.05 * V_{IAS} * \sqrt{(\alpha-\alpha_0) / (\alpha_P-\alpha_0)}$
  - $V_{Green\ Line} = 1.26 * V_{IAS} * \sqrt{(\alpha-\alpha_0) / (\alpha_P-\alpha_0)}$

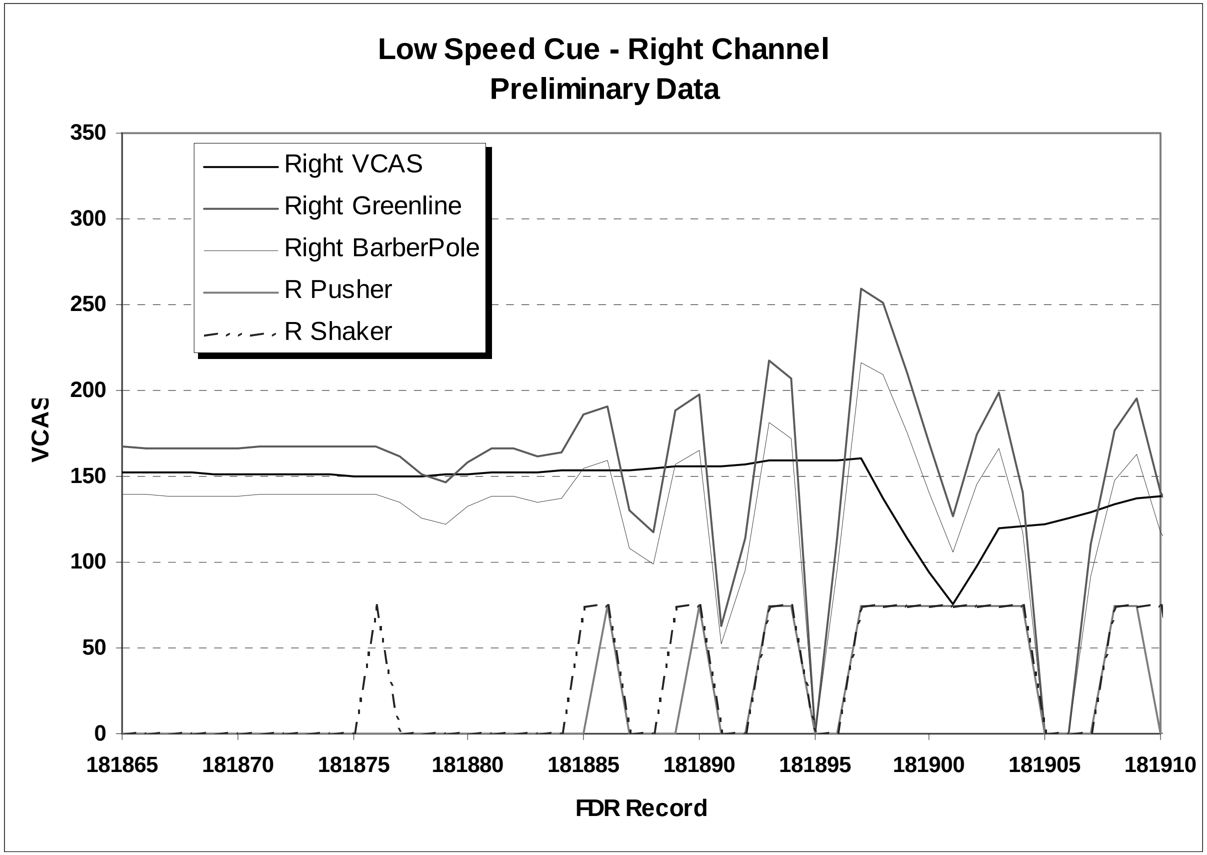
α_P - pusher firing angle

α_0 - zero lift AOA (-8 deg) - flap = 0 deg



Presentation to NTSB – November 2004
CRJ-200 Green Line and Barber Pole

- **Simulation time history of the low speed cue and green line as displayed to pilots at 41000 feet for the accident flight.**



4th November NTSB Performance Group Meeting - Action Closed

Presentation to NTSB – November 2004
CRJ-200 Green Line and Barber Pole

- **Various References**

The Normalized AoA is defined in Sextant document SPC/SE39951 002 iss 4 – Equipment Requirements SPC Version 09, this document provides the applicable firing angle and AOACL0 tables.

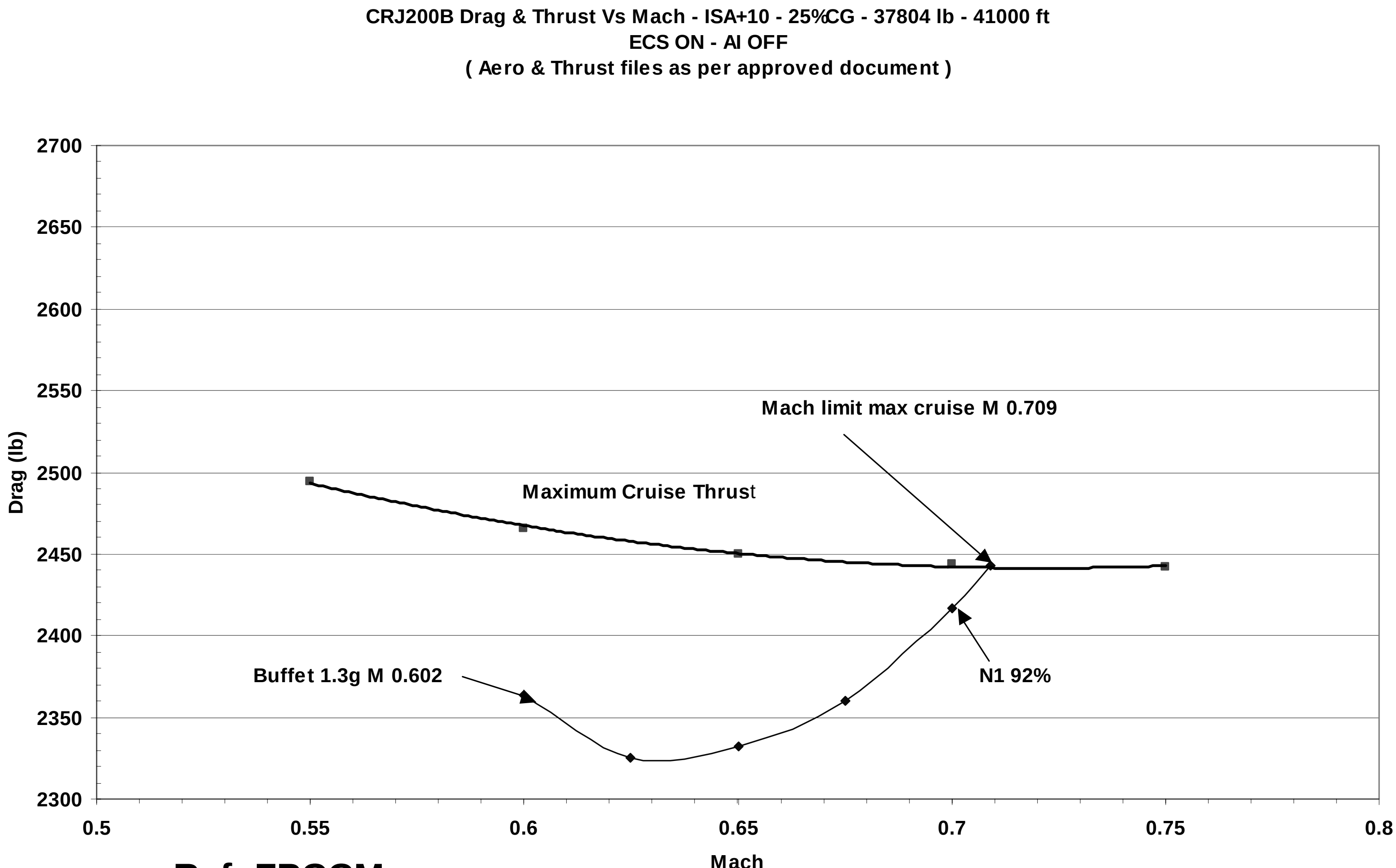
The equations for the cues are defined in Rockwell-Collins Document 613-6406-006 - EFD-4076 Canadair Regional Jet LRU Specification.

The constants are defined in Rockwell-Collins Document Configuration Module Definition ADC-850A 827-3394-154.

4th November NTSB Performance Group Meeting - Action Closed

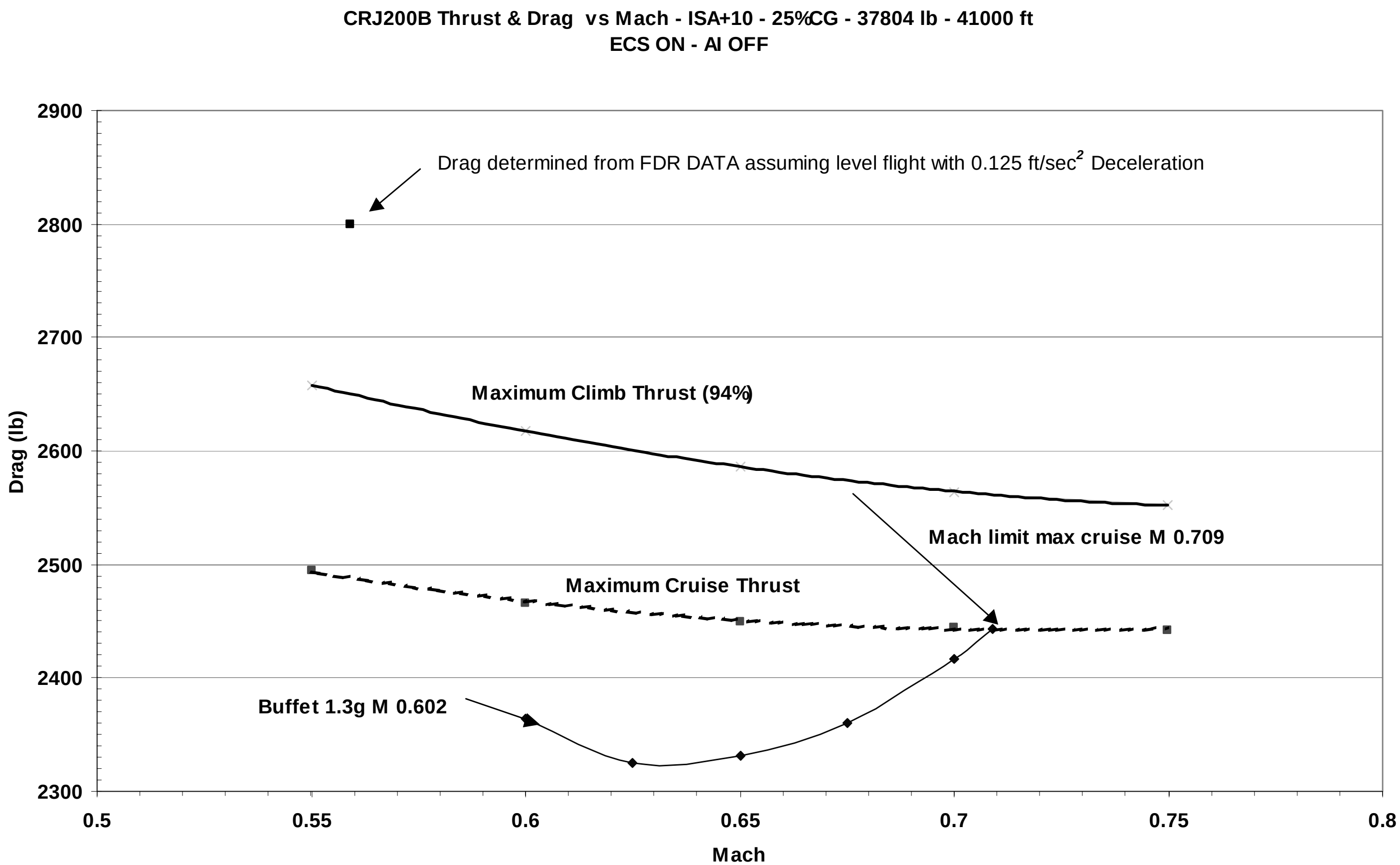
Where is the aircraft on the drag curve at 41,000 feet, and what is the excess thrust available.

Fig 1 FPCCM at 41,000 ft



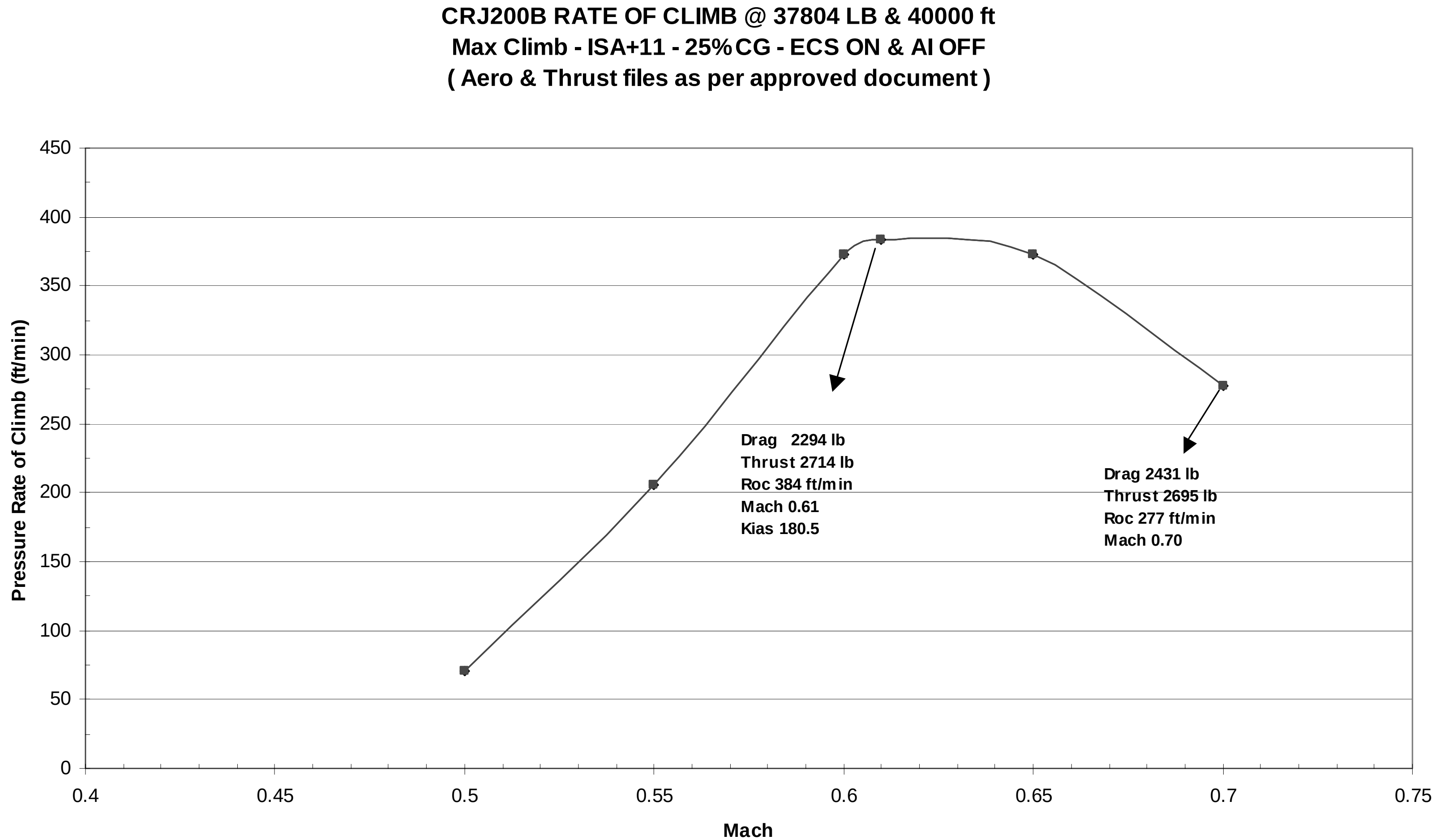
Ref: FPCCM

Where is the aircraft on the drag curve at 41,000 feet, and what is the excess thrust available.
Fig 2 at 41,000 ft



Ref: FPCCM

What is the drag and available thrust for a “normal” (AFM) climb. Figure 3.



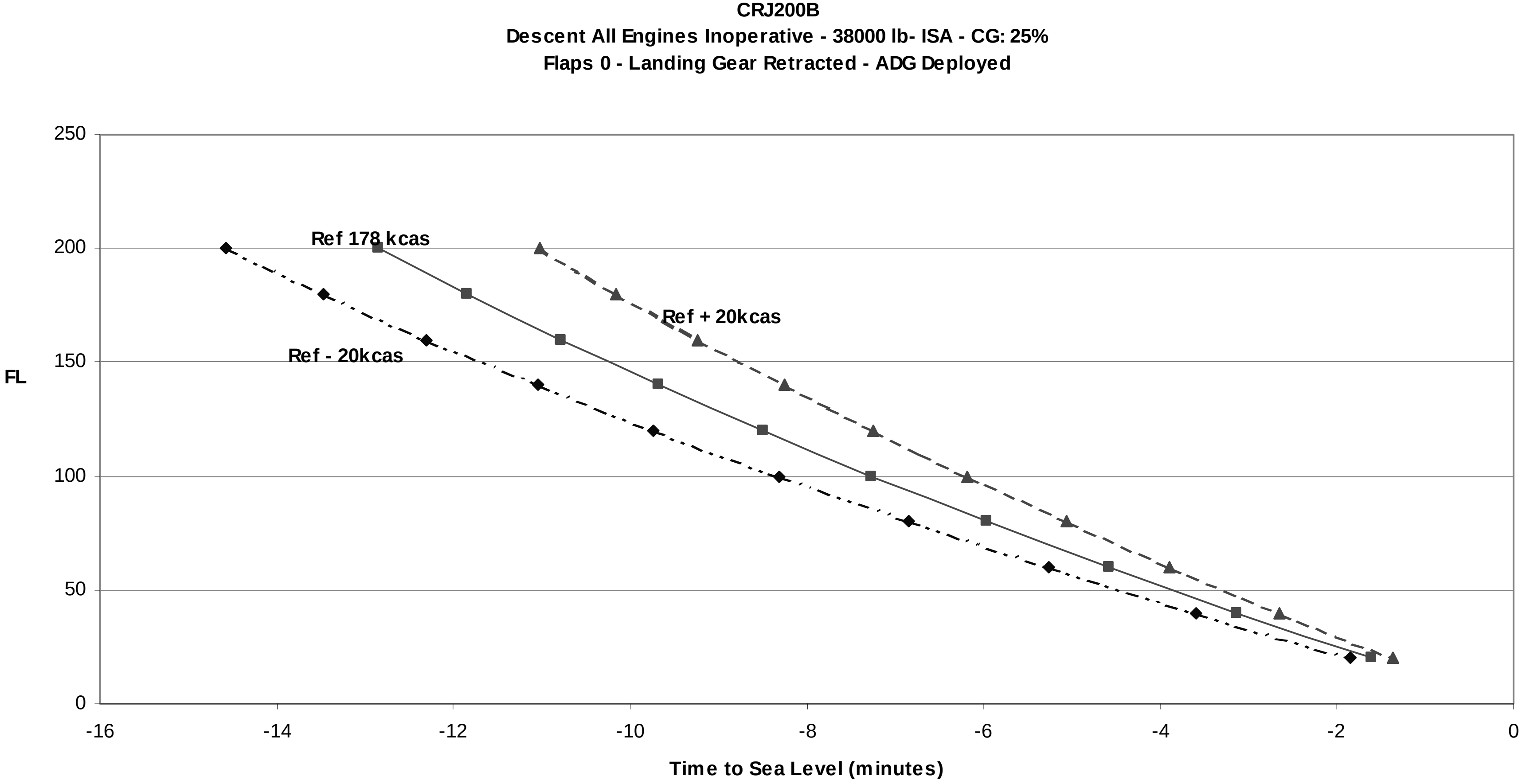
4th November NTSB Performance Group Meeting - Action Closed

Ref: FPCCM

Provide Max Glide performance information for trajectory after engine failures

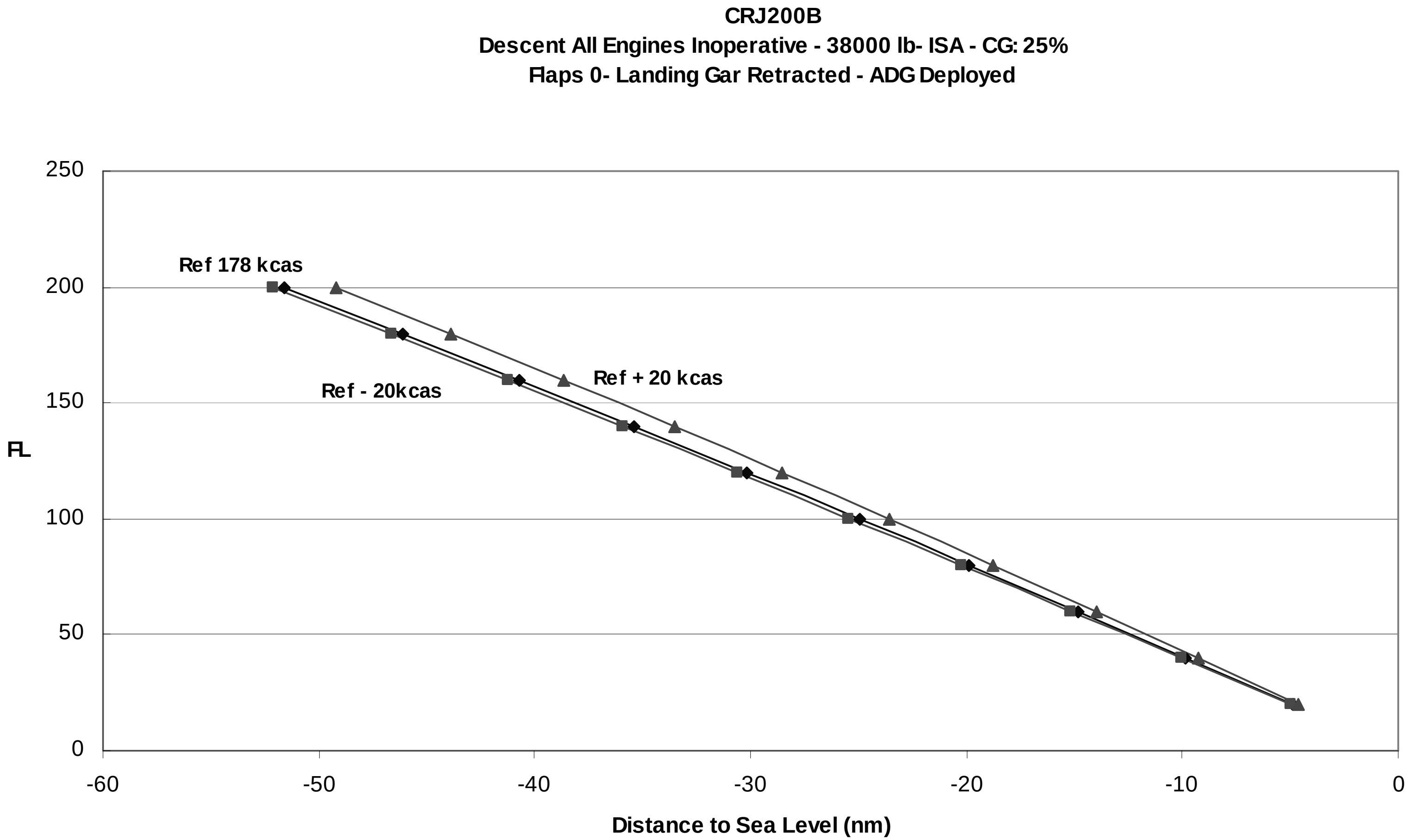
NTSB Will be provided with a copy of drift down for double engine failure in tabulated format (Pack 2)

How do actions such as operating at less or greater than recommended airspeed affect the glide and descent performance of the aircraft?



Ref: FPCCM

How do actions such as operating at less or greater than recommended airspeed affect the glide and descent performance of the aircraft?



4th November NTSB Performance Group Meeting - Action Closed

Request GE Engines to confirm the required N1 settings for the climb to 41000 feet from 36000 feet.

BA has validated the hand written GE N1 Setting for the maximum climb and we agree with their values within ± .1 N1.

Ref: FPCCM

4th November NTSB Performance Group Meeting - Action Closed

There are several portions of the ascent flight when the autopilot is disengaged, and for which control column forces are of interest. If possible, a calculation of control column force is requested for the following portions of the flight:

1. **Take-off Rotation**
2. **After autopilot disconnect at FDR SFRN 180238, start of climb from 15160 feet, up to 19,400 feet (SFRN 180300)**
3. **After autopilot disconnect at FDR SFRN 180567, increase in climb rate while passing through 24,500 until the autopilot is re-engaged at SFRN 180592**
4. **After the time of autopilot disconnect due to stick shaker at 41,000 feet, prior and during the loss of control.**

Will be provided in Pack 2

Presentation to NTSB – November 2004
CRJ-200 Aircraft Geometry

Aircraft Mass properties will be provided.

Pack 2

Aircraft Geometry:

Wing Ref Area = 520 sq ft
Wing sweep = 24.76 deg
MAC = 8.83 ft
Span = 67.85 ft (excluding winglets)
Wing root C/4 = 421 in. aft of nose
Ref: MAA-601R-110
root incidence = 3.4 deg
wing twist = 3.9 deg i.e. tip is at -0.5 deg
Ref: Drawing P601R10000
AOA vane location FS290 (nose is FS144) WL 94.35 (fuse max width WL 97.5)
Ref:Drawing 601R38330
The FDR accelerations come from a tri-axial accelerometer located at FS 515, WL 50, Left BL 7.6.
Ref: RAE-601R-119 for fuse station and drawing 601R52345 for BL and WL

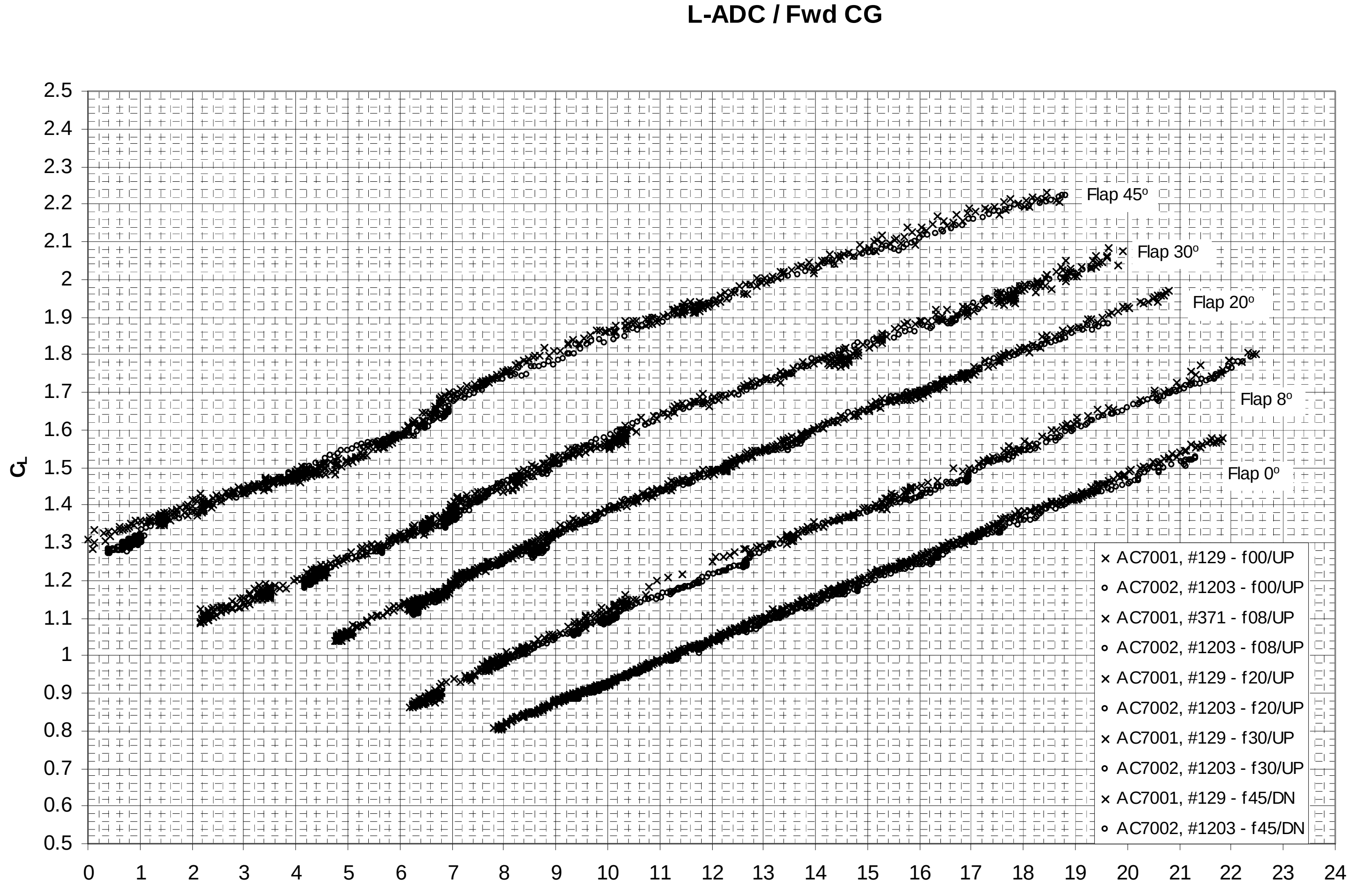
Presentation to NTSB – November 2004
CRJ-200 Aircraft Engine Parameters

Engine Parameters:
thrust vector pitch angle = 1.0 deg (up/forward)
thrust tow-out angle = 2.0 deg (thrust directed out/forward)
ram drag vector pitch angle = 3.5 deg (inlet face angled up/forward)
ram drag vector tow-out angle = 0 deg
FS thrust origin = 964.07
BL thrust origin = 84.0
WL thrust origin = 121.34
FS ram drag origin = 814.07
BL ram drag origin = 91.94
WL ram drag origin = 125.83

Note: FS is fuse station, BL is buttock line, WL is water line
Ref: MAA-601R-124

Presentation to NTSB – November 2004

Aerodynamics Data - CRJ-200 Lift Curve Slopes – Low Mach No.



Ref: MAA-601R-400

Presentation to NTSB – November 2004

Aerodynamics Data - CRJ-200 Lift Curve Slopes – High Mach No.

- The lift curve slopes at higher Mach numbers will be
- Provided in Pack 3.

Presentation to NTSB – November 2004

Aerodynamics Data - CRJ-200 Drag Polars

- The drag polars are in preparation. Pack 2

Chart (or relationship) for pitching moment as a function of angle of attack.

- **The pitch data is in preparation (Pack 3).**

Additional Question
(15th Nov. Group Member Introduction)

Air Driven generator Drag Coefficient used for double engine drift down calculation in the FPCCM
Ref: Hamilton Sundstrand

D1=C(1)*VE**2+C(2)*VE+C(3)
D2=D(1)*V**2+D(2)*VE+D(3)
Where:

C(1)=1.676797e-3	D(1)=5.948859e-4
C(2)=-2.114640e-4	D(2)=1.135835e-5
C(3)=1.106730e-2	D(3)=5.947184e-4

CDADG=(D1+D2)/(1481.35*DELTA*SWING*(M**2))
SWING=520 ft2

4th November NTSB Performance Group Meeting - Action Closed